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IDENTIFICATION AND MANAGEMENT OF WILDLIFE DAMAGE

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INTRODUCTION

Wildlife management is usually considered as the protection, enhancement, and nurturing of wildlife populations and the habitats needed for their well-being. However, many species at one time or another require management actions to reduce conflicts with people, other

Fig. 1. Examples of wildlife damage: A. elk (*Cervus elaphus*) consuming stored feed, B. aircraft collisions with birds, C. deer damage to habitat, D. wildlife-damaged corn, E. woodchuck damage in vineyards, and F. blackbird damage to sorghum.

wildlife species, or other resources. Examples include an airport manager modifying habitats to reduce gull activity near runways, a forester controlling pocket gophers to increase tree seedling survival in a reforestation setting, or a biologist trapping an abundant predator or competing species to enhance survival of an endangered species (Fig. 1).

Wildlife damage management is an increasingly important component of the wildlife profession because of expanding human populations and intensified land-use practices. Wildlife damage in the United States approaches $22 billion annually (Conover 2002). Concurrent with this growing need to reduce wildlife–people conflicts, public attitudes and environmental regulations are restricting use of some traditional tools of control, such as toxicants and traps. Agencies and individuals conducting control programs are being scrutinized more carefully to ensure their actions are justified, environmentally safe, humane, and in the best public interest. Thus, wildlife damage management activities must be based on sound economic, ecological, and sociological principles and conducted as positive, necessary components of overall wildlife management programs.

Wildlife damage management programs have 4 parts: (1) problem definition, (2) ecology of the problem species, (3) management methods application, and (4) evaluation of management effort. Problem definition refers to identification of the species and numbers of animals causing the problem, amount of loss or nature of the conflict, and other biological and social factors related to the problem. Ecology of problem species refers to understanding the life history of the species, especially in relation to the conflict. Management methods application refers to taking information gained from parts 1 and 2 to develop an appropriate management program to alleviate or reduce the conflict. Evaluation of management effort permits an assessment of the reduction in damage in relation to costs and impact of the management effort on target and nontarget populations. Emphasis is often placed on integrated wildlife damage management whereby several damage management methods are used in combination and coordinated with other management practices being used at that time.

We focus on techniques related to parts 1 (problem definition) and 3 (management methods application). Each major section on groups of wildlife species (birds, ungulates, etc.) has 3 parts: damage assessment, identification of damage by species, and control techniques; the last of these is an elaboration of those techniques listed under each species write-up.

LEGAL REQUIREMENTS FOR MANAGEMENT

Capturing or Killing Wildlife Species

Before action is taken to control or manage wildlife damage, it is important to understand the laws regarding both target and nontarget wildlife species. Management of most wild mammals, reptiles, and amphibians in the United States and Canada is the responsibility of the individual state or province. State or provincial laws regulate capture, possession, or killing of these vertebrates to control damage or nuisance situations. The main exception for mammals, reptiles, and amphibians in the United States relates to endangered and threatened species that are regulated federally by the Endangered Species Act of 1973, as amended.

Migratory birds, in contrast to other vertebrates, are managed in North America at the federal level under the Migratory Bird Treaty Act of 1918. The treaty has been amended several times and includes formal agreements with Canada, Mexico, Japan, and the former Soviet Union. Federal regulations in the United States and Canada require that a depredation permit be obtained from the U.S. Fish and Wildlife Service and Canadian Wildlife Service, respectively, before any person may capture, kill, possess, or transport most migratory birds to control depredations. No federal permit is required merely to frighten or herd depredating birds other than endangered or threatened species, and bald eagles (*Haliaeetus leucocephalus*) or golden eagles (*Aquila chrysaetos*).

Birds introduced to the United States, such as house sparrows (*Passer domesticus*), rock pigeons (*Columba livia*), European starlings (*Sturnus vulgaris*), and monk parakeets (*Myiopsitta monachus*) have no federal protection. Furthermore, a federal permit is not required to control yellow-headed (*Xanthocephalus xanthocephalus*), red-winged (*Agelaius phoeniceus*), tri-colored (*A. tricolor*), rusty (*Euphagus carolinus*), and Brewer's (*E. cyanocephalus*) blackbirds, brown-headed cowbirds (*Molothrus ater*), all grackles (*Quiscalus* spp.), crows (*Corvus* spp.), and magpies (*Pica hudsonica* and *P. nuttalli*) when they are committing or about to commit depredations npon ornamental or shade trees, agricultural crops, livestock, or wildlife or when they are concentrated in such numbers and manner as to constitute a health hazard. However, federal provisions do not circumvent any state laws or regulations which may be more, but not less, restrictive.

Anyone contemplating capture of or killing a vertebrate species for damage management must first review state or provincial regulations for that species. For birds and endangered or threatened species, federal regulations must also be followed. In addition to reviewing the legal aspects of species take, one must comply with state or local laws or ordinances regulating or restricting control methods. For example, use of foothold traps is banned in many states, and cities and townships often have noise ordinances which restrict or prohibit use of firearms, propane cannons, and other noise-generating devices commonly used to kill or haze animals and birds.

EPA Registration of Chemicals

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended, requires all pesticides and other chemicals used in controlling or repelling organisms in the United States to be approved and registered by the Environmental Protection Agency (EPA). The registration process is complex and costly, not only for new products but also for previously registered products being reviewed and re-evaluated (Goldman 1988). Products federally registered under Section 3 of FIFRA may not be available for use everywhere, because many states have their own registration requirements that might be more restrictive. Some products have Section 24c registrations that are valid only for specific states that have localized problems. Occasionally, products are available temporarily in specific localities for emergency use under Section 18 provisions of FIFRA. Finally, many of the registered compounds, such as vertebrate toxicants, are classified as "Restricted Use" pesticides. These products can only be used by, or under the direct supervision of, a certified pesticide applicator. Each state has its own certification requirements. Thus, anyone contemplating use of chemicals in wildlife damage management must review the status of and requirements for use of those chemicals in their particular locality. Jacobs (1994) provided a comprehensive list of registered chemicals for wildlife damage management.

BIRDS

Damage Assessment

Birds annually destroy many millions of dollars worth of agricultural crops in North America. The greatest loss appears to be from blackbirds feeding on ripening corn; a survey in 1993 conservatively estimated a loss of 285,000 metric tons, worth $30 million in the United States (Wywialowski 1996). Blackbird damage to sunflowers in the upper Great Plains states was estimated at $5 million in 1979 and $8 million in 1980 (Hothem et al. 1988). Damage by bird species to fruit crops such as cherries, grapes, and blueberries also can be severe in localized areas (Dolbeer et al. 1994*a*). Fish-eating birds can cause major losses at fish-rearing facilities (Glahn and Brugger 1995). Economic losses from bird strikes to aircraft in the United States are even more substantial than those in agriculture—at least $490 million annually for civil aviation (Clare et al. 2003) and $100 million for military aircraft (Conover et al. 1995).

Unlike most mammals, which are secretive when causing damage, birds are often highly visible and their damage is usually conspicuous. For these reasons, subjective estimares often overestimate losses as much as 10-fold (Weatherhead et al. 1982). Thus, objective estimates of bird damage to agricultural crops are important to accurately define the magnitude of the problem and to plan appropriate, cost-effective control actions (Dolbeer 1981).

To esrimate losses to birds in agricultural crops, one must devise a sampling scheme to select fields to be examined and plants or areas to be measured in the selected fields (Stickley et al. 1979). For example, to objectively estimate the amount of blackbird damage in a ripening corn or sunflower field, the estimator should examine at least 10 locations widely spaced in the field. If a field has 100 rows and is 300 m long, the estimator might walk staggered distances of 30 m along 10 randomly selected rows (e.g., 0–30 m in row 9, 31–60 m in row 20, and so on). In each 30-m length, the estimator should randomly select 10 plants and estimare the damage on each plant's ear(s) or seed head. Bird damage to corn can be estimated by measuring the length of damage on the ear (DeGrazio et al. 1969) or by visually estimating the percent loss of kernels (Woronecki et al. 1980) and converting to yield loss per hectare. Fruit loss can be estimated by counting numbers of undamaged, pecked, and removed fruits per sampled branch (Tobin and Dolbeer 1987). Sprouting rice removed by birds can be estimated by comparing plant density in exposed plots with that in adjacent plots protected by wire bird exclosures (Otis et al. 1983). The seeded surface area of sunflower heads destroyed by birds can be estimated with the aid of a clear plastic template (Dolbeer 1975) (Fig. 2).

Losses of agricultural crops to birds can be estimated indirectly through avian bioenergetics. By estimating the number of birds of the depredating species feeding in an

Fig. 2. Clear plastic template used to estimate damage to sunflower heads.

area, percentage of the agricultural crop in the birds' diet, caloric value of the crop, and daily caloric requirements of the birds, one can project the total biomass of crop removed by birds on a daily or seasonal basis (Weatherhead et al. 1982, White et al. 1985, Glahn and Brugger 1995).

Species Damage Identification

Most bird damage occurs during daylight hours, and the best way to identify the species causing damage is by observation. Presence of a bird species in a crop receiving damage does not automatically demonstrate the species is guilty, however. As one example, large, conspicuous flocks of common grackles (*Quiscalus quiscula*) in sprouting winter wheat fields were found, after careful observation and examination of stomach contents, to be eating corn residue from the previous crop. Smaller numbers of starlings were removing the germinating wheat seeds (Dolbeer et al. 1979). In another example, detailed research showed that great blue herons (*Ardea herodias*) at catfish farms primarily fed on diseased, dying fish (Glahn et al. 2002). The characteristics of damage for groups of birds are described in the sections below.

Gulls

Several gull species have adapted to existing in proximity to people, taking advantage of landfills and open trash containers for food. For example, a survey in 1994 revealed at least 15,000 nesting ring-billed (*Larus delawarensis*) and herring (*L. argentatus*) gulls in over 30 colonies on roofs in cities in the United States on the Great Lakes (Dwyer et al. 1996). Besides causing structural damage to roofs, gulls increasingly cause problems in urban areas by begging for food, defacing property, and contaminating municipal water supplies (Belant 1997). Gulls are a serious threat to flight safety at airports, representing 25% of the birds reported struck by civil aircraft during 1990–2002 (Cleary et al. 2003). In rural areas, gulls sometimes feed on fruit crops and farm-reared fish and ducklings, and compete with threatened bird species for nest sites. Damage management techniques to control gulls include habitat modification, netting and screening, frightening devices, toxicants, and shooting.

Blackbirds and Starlings

The term "blackbird" loosely refers to a group of about 10 species of North American birds, the most common of which are red-winged blackbirds, common grackles, and brown-headed cowbirds. The European starling, introduced to North America in the late 1800s, superficially resembles native blackbirds and often associates with them. Together, blackbirds and starlings constitnte the most abundant group of birds in North America, comprising a combined population of more than 500 million (Dolbeer 1990).

Blackbird damage to ripening corn, sunflowers, and rice can be serious (Dolbeer 1999). Much of this damage occurs in late summer during the "milk" or "dough" stage of seed development. The seed contents of corn are removed, leaving the pericarp or outer coat on the cob. Blackbird damage to sprouting rice in the spring can be serious in localized areas.

Starling depredations at feedlots in winter can cause substantial losses (Glahn et al. 1983). Although contamination of livestock feed by starling feces is often a concern of farmers, research indicated this contamination did not interfere with food consumption or weight gain of cattle and pigs (Glahn and Stone 1984) (Fig. 3). Starlings can also seriously damage fruit crops such as cherries and grapes (Dolbeer et al. 1994*a*).

Perhaps the greatest problem caused by blackbirds and starlings is their propensity to gather in large, nocturnal roosting congregations, especially in winter (Dolbeer et al. 1995a). The noise, fecal accumulation, and general nuisance caused by millions of birds roosting together near human habitations can be significant (White et al. 1985). Roosting birds near airports can create a safety hazard for aircraft and roost sites, if used for several years, can become focal points for the fungus that causes histoplasmosis, a respiratory disease in humans. Damage management techniques to control this group of birds include habitat modification, cultural practices (e.g., planting resistant crop varieties), netting and screening, frightening devices, repellents, toxicants, traps, and shooting.

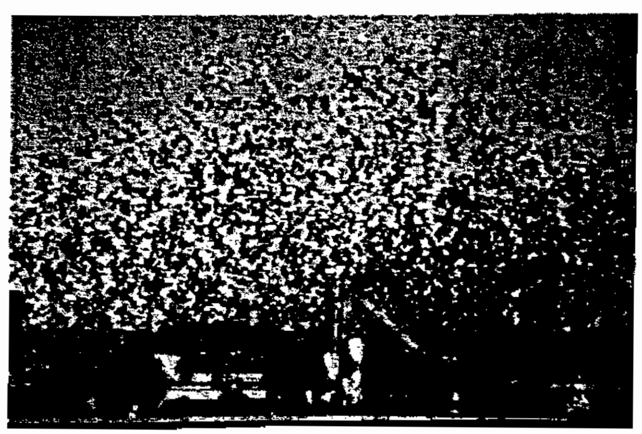

Fig. 3. Starlings congregate at feedlots where they consume and contaminate livestock feed.

Rock Pigeons and House Sparrows

Rock pigeons and house sparrows are urban and farmyard birds whose droppings deface and deteriorate buildings. Around storage facilities they consume and contaminate grain. Pigeons and sparrows may carry and spread diseases to people, primarily via their droppings (Weber 1979). Of particular concern, droppings that are allowed to accumulate over several years may harbor spores of the fungus that cause histoplasmosis. Sparrows build bulky grass nests in buildings, drain spouts, and other sites where they can cause fire hazards or other problems. Flocks of pigeons at airports pose a hazard to departing and arriving aircraft (Dolbeer et al. 2000). Damage management techniques for rock pigeons and house sparrows include netting and screening (such as networks of overhead wires), toxicants and capture agents (alpha-chloralose), trapping, and shooting.

Crows, Ravens, and Magpies

Crows, ravens, and magpies are demonstrated predators of eggs and nestlings of other birds. In certain situations, these species cause death of newborn lambs or other livestock by pecking their eyes. Magpies at times peck scabs on freshly branded cattle.

Crows occasionally damage agricultural crops such as corn, apples, and pecans. Most of this loss is localized and minor. Crow damage to apples can be distinguished from damage by smaller birds by the deep (up to 5 cm), triangular peck holes (Tobin et al. 1989). Roosting congregations of crows in trees in parks and cemeteries may cause nuisance problems because of noise and feces. Damage management techniques for corvids include frightening devices, toxicants, traps, and shooting.

Herons, Egrets, and Cormorants

These species can concentrate at fish-rearing facilities and cause substantial losses. Salmon smolts released in rivers in the northeastern United States have suffered heavy depredation by double-crested cormorants (*Phalcrocorax auritius*). In recent years, cormorants have caused serious losses at commercial fish ponds in the southern United States (Glahn and Brugger 1995). They are also implicated in impacting fisheries in the Great Lakes. Observations at night may be necessary to identify the depredating species, because some species are nocturnal. Damage management techniques for this group include habitat modification, netting and screening, frightening devices, and shooting.

Raptors

Raptors most often implicated in predation problems with livestock (primarily poultry) are red-tailed hawks (*Buteo jamaicensis*), great horned owls (*Bubo virginianus*), and northern goshawks (*Accipiter gentilis*) (Hygnstrom and Craven 1994). Unlike mammalian predators, raptors usually kill only a single bird a day. Raptor kills usually have bloody puncture wounds in the back and breast. Owls often remove the head of their prey. Raptors generally pluck birds, leaving piles of feathers. Plucked feathers that have small amounts of tissue clinging to their bases were pulled from a cold bird that probably died from other causes and was scavenged by the raptor. If the base of a plucked feather is smooth and clean, the bird was plucked soon after being killed. Because raptors have large territories and are not numerous in any one area, removal of 1–2 individuals will generally solve a problem, although damage areas along migration routes can be problematic.

Golden eagles occasionally kill livestock, primarily lambs and goat kids on open range. Livestock predation can be locally severe in sheep-producing areas from New Mexico through Montana (Phillips and Blom 1988). Close examination is needed to identify an eagle kill. Eagles have 3 front toes opposing the hind toe, or hallux, on each foot. The front talons normally leave punctures about 2.5–5.0 cm apart in a straight line or small "V", and the wound from the hallux will be 10–15 cm from the middle toe. In contrast, mammalian predators usually leave 4 punctures or bruises from their canine teeth. Talon punctures are usually deeper than tooth punctures, and there is seldom any crushing of tissue between the talon punctures. If a puncture cannot be seen from the outside, the carcass should be skinned to identify the pattern of talon or tooth marks. Often a young lamb is killed with a single puncture from the hallux in the top of the skull and punctures from the 3 opposing talons in the base of the skull or top of the neck (O'Gara 1978*b*, 1994).

Raptors, especially red-tailed hawks and American kestrels (*Falco sparverius*), are frequently attracted to grassland areas at airports to hunt for rodents and large insects. These birds can cause serious damage to aircraft when drawn into engines (Dolbeer et al. 2000). Damage management techniques include habitat modification, netting and screening, frightening devices, traps (accompanied by translocation), and shooting.

Woodpeckers

Woodpeckers may cause damage to buildings with wood siding, especially cedar and redwood (Evans et al. 1983, Belant et al. 1997). The birds peck holes to locate insects, store acorns, or establish nest sites. They also damage utility poles. Sapsuckers attack trees to feed on sap, bark tissue, and insects attracted to the sap. Their feeding can sometimes kill the tree or degrade the quality of wood for commercial purposes. Woodpeckers occasionally annoy homeowners by hammering on metal rain gutters and stovepipes to advertise their territories. Damage management techniques for this group include cultural practices (exclusion), frightening devices, repellents (sticky tactile compounds to prevent birds from landing on structures), traps (snap and live traps), and shooting.

Ducks, Geese, and Sandhill Cranes

Damage by ducks and cranes to swathed or maturing small-grain crops during the autumn harvest is a serious, localized problem in the northern Great Plains (Knittle and Porter 1988). Damage occurs from direct consumption of grain and from trampling, which dislodges kernels from heads.

Canada (*Branta canadensis*) and snow geese (*Chen caerulescens*) grazing on winter wheat and rye crops can reduce subsequent grain and vegetative yields (Kahl and Samson 1984, Conover 1988). Canada geese also can be a serious problem to sprouting soybeans in spring and in fields of standing corn in autumn. Canada geese have adapted to suburban environments in the past 30 years, creating nuisance problems through grazing, defecation, and nest defense (Smith et al. 1999). Canada geese are the most serious bird threat to aircraft (Dolbeer et al. 2000). Damage management techniques for ducks, geese, and cranes include habitat modification (planting lure crops), netting and screening (such as networks of overhead wires), frightening devices, capture agents (alpha-chloralose), traps (accompanied by translocation), and shooting (hunting).

Control Techniques

Habitat Modification and Cultural Practices

Habitat modification and cultural practices can be implemented in many situations to make roosting, loafing, or feeding sites less attractive to birds. Although the initial investment of time and money may be high, modifications often provide long-lasting relief. Thinning or pruning vegetation can cause roosting birds such as blackbirds and starlings to move, often increasing the commercial or aesthetic value of the trees or marsh at the same time (Micacchion and Townsend 1983, Leitch et al. 1997). Eliminating standing water and prohibiting nearby landfills can reduce gull activity at airports. The U.S. Federal Aviation Administration's policy is that solid-waste disposal sites should not be located within 3 km of any runway used by turbojet aircraft (Cleary and Dolbeer 1999).

Use of lure crops, where waterfowl or blackbirds are encouraged to feed, may be cost-effective in reducing damage to nearby commercial fields of grain and sunflowers where bird-frightening programs are in place (Cummings et al. 1987). Bird-resistant cultivars of corn, sunflower, and sorghum have proven effective in reducing damage. For example, varieties of sweet and field corn with ears having long, thick husks difficult for blackbirds to penetrate experience less damage than varieties with ears having short, thin husks (Dolbeer et al. 1988*b*, 1995*b*). Certain varieties of cherries are more vulnerable to bird damage than others (Tobin et al. 1991). Planting crops so they do not mature unusually early or late also can reduce damage by blackbirds (Bridgeland and Caslick 1983). Control of insects in cornfields can make those fields less attractive to blackbirds and reduce subsequent damage to corn (Dolbeer 1990).

Netting and Screening

Plastic netting is cost effective for excluding birds from individual fruit trees or high value crops such as blueberries or grapes (Fuller-Perrine and Tobin 1993). Netting or wire screening can be used to exclude birds from rafter areas of airport hangars, undersides of bridges, fish hatcheries, and vent openings of buildings. Ledges on buildings designed at, or modified to, a 45° angle will prevent perching or nesting by birds. Electrically charged wires or arrays of wire (porcupine wire) or plastic spikes installed on ledges and other sites can prevent birds from perching.

Parallel strands of monofilament lines or wires placed at 2.5- to 12-m intervals over ponds, landfills, and other structures can reduce gull activity (Blokpoel and Tessier 1984, Belant and Ickes 1996). Monofilament lines at 30- to 60-cm intervals repelled house sparrows from feeding sites (Agüero et al. 1991). Gulls and house sparrows are reluctant to fly through these strands even though the spacing is larger than their wingspans. Overhead lines have also excluded birds from fish hatcheries. Heavy plastic (PVC) strips hung from open doorways will help exclude starlings and other birds from buildings (Johnson and Glahn 1994).

Frightening Devices

Many sonic and visual devices, homemade and marketed commercially, are available to frighten birds. Birds usually habituate to such devices, no matter how effective they may be initially. Thus, 2 important rules are: (1) do not rely solely on one type of device for frightening, and (2) vary the timing of deployment and location of devices. More succinctly, frightening devices are only as effective as the person deploying them.

Probably the most widely used frightening device is the propane cannon, which produces a loud explosion at timed intervals. Several models are marketed, including ones with automatic timers, remote activation, and rotating barrels. To be effective in frightening birds from crops, at least one cannon should be used for each 2 ha and cannons should be moved every few days. An occasional shotgun patrol to reinforce the cannons is important (Dolbeer 1980), using either live ammunition or shell crackers. Shell crackers, fired from a 12-gauge shotgun, shoot a projectile that explodes 50–75 m away. Other pyrotechnic devices for frightening birds include rockets and whistle bombs (Cleary and Dolbeer 1999).

Recorded alarm and distress calls of birds broadcast over a speaker system may work well to frighten birds (Bomford and O'Brien 1990). Some airports have speakers mounted on vehicles from which personnel broadcast amplified calls for bird species frequently encountered during runway patrols. Shooting at birds with a shotgun is often used to reinforce the distress calls. These calls are commercially available.

Ultrasonic devices emitting sounds with frequencies above the level of human hearing (20,000 Hz) are marketed for bird control in and around buildings. However, objective field tests have not demonstrated effectiveness of ultrasonic devices (Woronecki 1988). Most birds detect sounds in about the same range of frequencies as do humans.

Flags, helium-filled balloons with and without eyespots, and hawk kites suspended from balloons or bamboo poles have been used with some success to repel birds (Conover 1984, Seamans 2002). Mylar flags, 15 cm × 1.5 m in size, have been used to exclude geese from agricultural crops and gulls from loafing sites (Heinrich and Craven 1990, Belant and Ickes 1997). Ten flags per 4 ha are recommended. Reflecting tape made of mylar, placed in parallel lines at 3- to 7-m intervals, reduced blackbird numbers in agricultural fields (Dolbeer et al. 1986). Dead vulture effigies suspended from structures have caused abandonment of vulture roosts (Tillman et al. 2002). Inflatable human effigies have been used to disperse cormorants from aquaculture facilities (Stickley et al. 1995). Lasers have been effective in dispersing Canada geese, cormorants, crows, and other species from night roosts (Blackwell et al. 2002).

Blackbird roosts containing up to several million birds can be moved by use of a combination of devices, particularly recorded distress calls, shell crackers, rockets, and propane cannons (Mott 1980). Strobe lights placed in the roost are also helpful. The operation should begin before sunset, when the first birds arrive, and end at dark. People with shotguns and shell crackers should be stationed on the perimeter of the roost to intercept flight lines as they enter the roost. Three to 5 nights of harassment may be required to achieve complete dispersal. If not modified as a part of the dispersal program, the habitat of the roost should be altered (e.g., tree thinning) after birds have been hazed from the site to discourage the roost from reforming.

Repellents

Most birds have poor senses of smell and taste in general; hence, repellents targeting these senses are usually not effective (Rogers 1974, Belant et al. 1998*b*). For example, naphthalene crystals, although registered as an odor repellent for starlings, rock pigeons, and house sparrows in indoor roosts, have not been effective in field trials (Dolbeer et al. 1988*a*). Taste repellents used as seed treatments to prevent consumption of germinating seeds are also of questionable value (Heisterberg 1983).

In contrast, chemicals that produce illness or adverse physiological response upon ingestion (i.e., conditioned aversion) appear to work well as bird repellents (Rogers 1974). Methiocarb, a carbamate insecticide, is a condition-aversive repellent that has been used as a seed treatment for corn (applied as a powder to the seed at planting) and as a spray treatment for ripening cherries and blueberries (Dolbeer et al. 1994*a*). Another conditioned aversion repellent, anthraquinone, has shown effectiveness in repelling geese from feeding on turf (Dolbeer et al. 1998). Formulations containing methyl anthranilate, a chemical that irritates the trigeminal nerve in birds, have shown some success as a repellent (Belant et al. 1995).

Toxicants and Capture Agents

The use of toxic baits to control pest birds without harming nontarget organisms requires patience and a thorough understanding of the habits and food preferences of target species. Prebaiting for several days with untreated bait is critical, not only to enhance bait acceptance but to assess the amount of toxic bait to be used and possible nontarget hazards. Nearby sources of preferred food should be restricted as much as possible during the prebaiting period. Strict control must be maintained over the toxic bait. Dead birds should be collected at least daily and buried.

DRC-1339 is an EPA-registered toxicant incorporated into poultry pellets and marketed as Starlicide Complete® for control of starlings at feedlots and poultry yards. DRC-1339, incorporated into bread baits, also is registered for control of certain gull species that compete with threatened bird species for nest sites (Seamans and Belant 1999). DRC-1339 affects the renal and circulatory systems, killing the bird 24–72 hours after ingestion.

Avitrol® is an EPA-registered frightening agent. The active ingredient, 4-aminopyridine, when ingested in small doses, causes the affected bird to emit distress calls while flying in erratic circles. The affected bird usually dies within 0.5 hour, but its initial behavior can act to frighten other birds away. Avitrol is registered for use on rock pigeons, gulls, house sparrows, starlings, and blackbirds around structures and nesting and roosting sites, starlings at feedlots, gulls at airports, and blackbirds in corn and sunflower fields. Avitrol-treated bait is usually diluted 1:10 or 1:99 with untreated bait so that only a portion of the birds feeding is affected (Woronecki et al. 1979).

Alpha-chloralose is a drug that can be mixed with corn or bread baits to immobilize and capture nuisance waterfowl, American coots (*Fulica americana*), and rock pigeons. Birds typically become immobilized 30 minutes after ingesting bait and fully recover 4–24 hours later (Woronecki et al. 1992). Alpha-chloralose is restricted by the U.S. Food and Drug Administration for use by U.S. Department of Agriculture biologists in the Wildlife Services Program (Belant et al. 1999).

Traps

Starlings and certain blackbird species often can be captured in decoy traps. A decoy trap is a large (e.g., 6 × 6 × 1.8 m) poultry wire or net enclosure containing 5–20 live decoy birds, food, water, and perches. Birds enter the trap by folding their wings and dropping through an opening (0.6 × 1.2 m) in the cage top covered with 5- × 10-cm welded wire to reach the food (cracked corn, millet) below. Decoy traps have been used to reduce local populations of starlings, to remove cowbirds from the nesting area of the endangered Kirtland's warbler (*Dendroica kirtlandii*) (Kelly and DeCapita 1982), and vireos (*Vireo* spp.) in Oklahoma and to capture blackbirds for banding and research purposes. Rock pigeons and house sparrows can be captured in walk-in or funnel traps (Corrigan 1989) (Fig. 4). Mist nets can be used to remove house sparrows around barns and small farms (Plesser et al. 1983).

Various trapping techniques are used to capture raptors, including bal-chatri traps, harnessed rock pigeons, Swedish goshawk traps, bow-nets, and padded foothold traps (Bloom 1987). Raptors often become wary to one trapping technique, requiring use of 2 or 3 different techniques before successfully capturing some birds. Golden eagles preying on livestock can be captured for translocation with a net gun fired from a helicopter (O'Gara and Getz 1986).

Shooting

Shooting can be effective for reducing local populations of depredating or hazardous birds (Dolbeer et al. 1993). For example, a skilled shooter with an air rifle (pellet gun) can efficiently remove rock pigeons roosting and nesting inside buildings. For large populations of flocking birds, shooting may have little impact on the overall population (Dolbeer 1998) but can enhance efforts to repel birds from

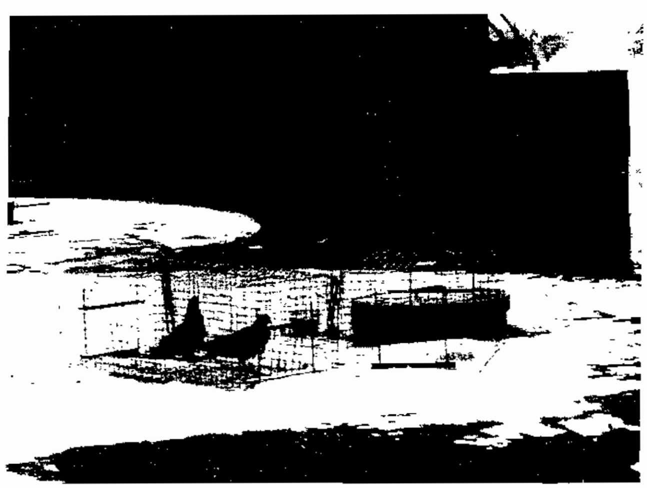

Fig. 4. Walk-in traps set on a grain elevator to catch rock pigeons.

areas needing protection (Murton et al. 1974). This concept has been promoted in Wisconsin through a hunter referral program in which farmers allow goose hunters to shoot in agricultural fields experiencing chronic damage (Heinrich and Craven 1987).

UNGULATES

Damage Assessment

In North America, ungulates associated with resource damage are typically members of the deer (Cervidae) and swine (Tayassuidae and Suidae) families. They include native (e.g., white-tailed deer [*Odocoileus virginianus*], elk, collared peccary [*Pecari tajacu*]) and introduced species (e.g., fallow deer [*Dama dama*], red deer [*Cervus elaphus barbarus*], feral swine, feral goats). Populations of some species of ungulates, primarily white-tailed deer, elk, and feral swine, have been increasing steadily in recent decades (Gipson et al. 1998). Feral swine include domestic swine that have reverted to living in the wild, exotic wild boar (*Sus scrofa scrofa*) that were introduced, and hybrids (Mungall 2000). Overabundant populations of ungulates can cause a variety of types of damage at landscape, regional, and local scales. Ungulates damage plants in agricultural, forestry, natural, and urban settings resulting in losses in the hundreds of millions of dollars each year (Fig. 5). They can also transmit diseases to livestock and humans and threaten human safety when involved in collisions with vehicles—including airplanes. Repair costs associated with deer–vehicle collisions exceed $1.6 billion annually. Conover (2002) discussed the economics associated with types of damage caused by deer and other wildlife.

Ungulates feed on various agricultural crops, especially soybeans, corn, and alfalfa. Yield reductions in soybean fields are most severe when feeding occurs during the first week of sprouting (DeCalesta and Schwendeman 1978), and corn yield is impacted most when feeding occurs during the silking-tasseling stage (Hygnstrom et al. 1991). Ungulates, especially when food stressed, can also cause damage to stored crops (VerCauteren et al. 2003*c*).

Ungulates cause damage to trees, primarily from browsing and antler rubbing. Deer browsing in late winter on

Fig. 5. Urban and rural damage caused by deer includes: A. deformation of individual trees by browsing, B. stripping of branches and bark through antler rubbing, C. creation of a browse line, and D. crop damage.

buds of fruit trees can reduce yields. Similar browsing on nursery plants and in Christmas-tree plantations can negatively impact market values (Scott and Townsend 1985). Browsing of hardwood saplings and young Douglas-fir (*Pseudotsuga menziesii*) trees in regenerating forests can reduce growth rates, mis-shape trees, and even cause plantation failures (Crouch 1976, Tilghman 1989). Antler rubbing, to remove velvet and hone sparring skills for the mating season (rut), can also damage or kill trees. On larger spatial scales, overabundant populations of ungulates have had deleterious impacts on entire biotic communities, impacting flora and fauna (Miller et al. 1992, DeCalesta 1994, Waller and Alverson 1997).

Unlike other ungulates that are strictly herbivorous, feral swine are omnivorous. Besides being destructive to vegetation, they can be predatory and have had deleterious impacts on fauna (Roythe 1995).

Species Damage Identification

Identification of ungulate damage is not difficult, as the culprits are often observed causing damage. Also, their tracks are readily identifiable. Cervids lack upper incisors and, therefore, leave a rough, shredded break on the twigs and stems they browse. Vegetation fed upon by rodents and lagomorphs, however, shows a neat, sharp-cut edge. Evidence of browsing damage higher than rodents or lagomorphs can reach is indicative of ungulate damage (realizing these smaller animals can cause damage higher on vegetation when standing on snow). Mule (*O. hemionus*) and white-tailed deer damage typically occurs from ground level to 1.8 m and they seldom browse on branches >2.5 cm in diameter. Moose (*Alces alces*) and elk damage can reach 3 m in height and they will use their incisors to scrape the bark of aspen (*Populus tremuloides*) trees. In the fall, male cervids rub the velvet from their antlers, often removing tree bark in the process. Scarring is generally confined to the trunk up to 1 m high for mule and white-tailed deer and up to 2 m for elk. Rooting of feral swine is readily visible as, through their omnivorous feeding, they turn over soil and in the process cause damage to pastureland, crops, and native plants.

Control Techniques

The public generally approves of nonlethal management techniques, especially in urban settings, where traditional hunting may not be safe, yet damage levels are high. While population reduction through lethal means is often necessary to reduce ungulate damage to tolerable levels, there are many nonlethal strategies that may have a role in a comprehensive ungulate management program. However, the limited effectiveness and high cost of nonlethal strategies frequently make them economically impractical, even when used in conjunction with lethal strategies.

Habitat and Food Modifications

Reduction of permanent cover in a local area could reduce ungulate carrying capacity, but would also destroy habitat that is important for other wildlife. Selecting plants that are less preferred foods or are resistant to ungulate damage can minimize ungulate damage in urban areas and to human-made plantings. Craven and Hygnstrom (1994) present a list of common plants and their susceptibility to damage. Crops should be harvested as early as possible to minimize the time they are susceptible to damage. Researchers are beginning to develop genetic strains of plants that are less palatable to ungulates; advancements in this area may greatly improve our ability to reduce damage through habitat modification. Lure crops have been used to draw ungulates from more valuable crops, but providing additional forage for ungulates could lead to higher densities, resulting in increased damage. Similarly, feeding and baiting ungulates ultimately leads to increased damage. Baiting can result in higher reproductive and survival rates and lead to congregated (Doenier et al. 1997) and tame populations. It also makes the ungulate population more susceptible to diseases (Davidson and Nettles 1997), some of which can be spread to other species of wildlife and livestock.

Fencing and Barriers

Frequently the only effective nonlethal method to minimize ungulate damage is fencing. Several fence designs are available (Fig. 6), although an effective yet low-cost fence

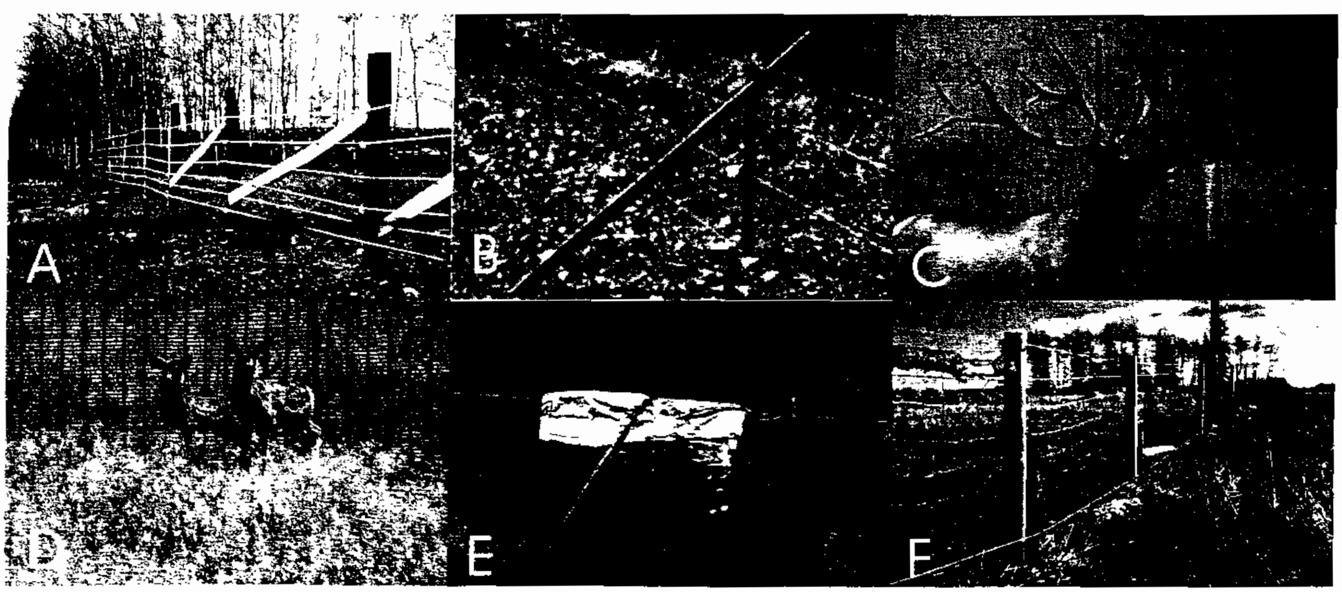

Fig. 6. Examples of fence types: A. electrified poly-wire, B. slanted high-tensile wire, C. high, woven wire, D. plastic "snow fence", E. peanut butter-baited electric fence, and F. low, woven wire with electrified wire.

design has yet to be perfected. Fencing typically acts in 1 of 2 ways to exclude ungulates: as a physical barrier or as a psychological barrier. The standard deer fence, a woven-wire fence 2.4-m high, is a physical barrier and greatly reduces the possibility of an animal passing through, over, or under. Conversely, a single- or double-strand electric poly-tape fence acts as a psychological barrier through aversive conditioning. The training occurs when an animal attempts to breach the fence and receives a powerful electric shock. Some fences incorporate both concepts, such as a 2.4-m high, 11-strand high-tensile electric fence with the goal of increasing the efficacy of the barrier. Broad classes of fence designs include: wire mesh, modified woven-wire mesh, high-tensile electric, barbed wire, slanted, and temporary electric poly tape, wire, or rope (Table 1). Variables to be considered when deciding on fence design include: level of protection desired from the fence, seasonal presence of the resource being protected, the animal's ability to breach different fence designs, motivation to breach, behavioral characteristics and physical abilities of the species being excluded, costs associated with constructing and maintaining the fence, longevity of the fence, and possible negative effects of erecting a fence (VerCauteren aud Lavelle 2005). While fencing may have the potential to greatly reduce damage, its expense may not make it economical, especially in situations where the value of the resource being protected is low and the area to be protected is large. In addition, size, shape, and perimeter of the area to be protected influence the amount of fencing required and, thus, the cost (Conover 2002).

Alternatives to fencing include tree cylinders, tree wraps, and bud caps, all of which provide protection for individual trees or tree parts (DeCalesta and Witmer 1994). These devices reduce damage by minimizing access to the roots, stems, vegetation, and growing points until plants are no longer highly vulnerable to serious damage. Because these damage reduction methods do not completely exclnde animals from large portions of their habitat, they may be a preferred option over fencing. One must consider number of plants (usually tree seedlings) and size of the area being protected, because at slightly <$1.00 to >$3.00/seedling protected, individual plant protection expenses may approach the expense of fencing. Chicken-wire cylinders, photodegradable polypropylene cylinders, and a variety of flexible mesh sleeves can effectively protect seedlings. Because use of a protective cylinder provides protection only until the terminal bud protrudes from the top of the cylinder and then becomes accessible to ungulates, it may be advantageous to apply bud caps at this time.

Dogs as a Deterrent

Dogs within the perimeter of invisible fencing systems that surround agricultural crops have been shown to reduce damage by deer (Beringer et al. 1994) and several producers are actively using dogs to protect orchards and annual crops. Dog selection, training, and care are important components to the success of this strategy. Use of dogs also has the potential to reduce transmission of disease in wild ungulates to livestock. Dogs also serve to control damage from other wildlife species, such as raccoons (*Procyon lotor*).

Repellents

Several repellents have been evaluated to assess their ability to reduce ungulate damage (El Hani and Conover 1997, Nolte and Wagner 2000). There are 3 general categories of repellents: odor, contact, and systemic. Odor repellents are designed to repel animals from an area and either mimic predator odors (e.g., human or coyote [*Canis latrans*] hair) or are repugnant (e.g., moth balls, bone tar). Contact repellents are applied directly to the resource to be protected, and are therefore ingested by the offending animal. They function by creating a gustatory aversion or causing illness (aversive conditioning). Systemic repellents are incorporated into plants, either naturally (e.g., tannins) or through genetic manipulation.

Currently, use of repellents is best suited to settings with high-value plants (e.g., orchards, nurseries, gardens, ornamentals) because costs, application restrictions, and variable effectiveness make them impractical for use on low-value resources (i.e., row crops, pasture) (DeNicola et al. 2000). Repellents cannot be expected to totally eliminate damage (Craven and Hygnstrom 1994) and are at best a short-term protection measure. Repellents are

Table 1. Fence types including cost, height, efficacy level, longevity (years), and level of required maintenance.

Fence type	Cost/m ($)	Height (m)	Efficacy	Longevity	Maintenance
Woven wire or v-mesh	>6.00	3.64	High	30 to 40	Low
Chain link	>6.00	2.4	High	30 to 40	Low
Polypropylene mesh	>6.00	2.4	Moderate-high	10 to 20	Medium
New poly-rope (9-strand)	4.00–6.00	1.82	Moderate	20 to 30	Medium
Welded-wire mesh	4.00–6.00	3.64	High	20 to 30	Low
Plastic snow fence	4.00–6.01	2.12	Moderate-high	5 to 10	Medium
Modified woven wire with 2-strand barbed wire	4.00–6.02	2.4	Moderate-high	20 to 30	Medium
Modified woven wire with 5-strand high tensile	4.00–6.03	2.4	Moderate-high	20 to 30	Medium
Barbed-wire (18-strand)	2.00–4.00	2.4	Moderate	20 to 30	Medium
Non-electrified 15-strand high tensile	0.50–2.00	2.4	Moderate	20 to 30	Medium
New Hampshire (onset 3-strand)	0.50–2.01	1.05	Low	20 to 30	High
Slanted 7-strand high tensile	0.50–2.02	1.5	Moderate	20 to 30	High
Penn State 5 (5-strand electrified high tensile)	0.50–2.03	1.12	Moderate	20 to 30	High
Two-strand polytape	0.50–2.04	0.9	Low	5 to 10	High
Non-electrified 8-strand high teusile	0.50–2.05	1.82	Low	20 to 30	High
Peanut butter-baited electric	<0.50	1.12	Low	10 to 20	High

most effective on vegetation during the dormant season, but results are inconsistent. Even under optimal conditions, some damage usually occurs. Factors such as ungulate population density, availability of alternate foods, target plant species, weather, repellent concentration, and duration of the problem can influence repellent effectiveness.

The history of pesticide regulations has compromised the effectiveness and marketing of repellents. In 1978, amendments to the Federal Insecticide Fungicide and Rodenticide Act (FIFRA) gave the Environmental Protection Agency (EPA) the option to waive data submission requirements for efficacy of pesticides. The EPA took advantage of this provision except for certain public-health uses (Jacobs 2002). In 1982, the waiver was extended to all vertebrate pesticide products but, within 2 years, data submission requirements for public-health uses were fully reinstated with the added proviso that the waiver applied only to the submission of data and that EPA could request efficacy data for any product at any time. Armed with this option, the agency began to require submission of efficacy data for reregistration of products claimed to repel vertebrate pests; the efficacy of many such products had been in question for several years. The Office of Pesticide Programs reversed this policy in 1995, except for products making claims to repel pests of public health significance (Jacobs 2002). The result of these legislative actions is that efficacy data are not required for most products making claims to repel vertebrate pests, because these products are not typically labeled for public health uses (Jacobs 2002). As a result, there are many repellents currently on the market and many are not effective.

Frightening and Hazing

Propane cannons, flashing lights, shell crackers, and other sonic devices used near a resource can provide temporary relief from ungulate damage. The proper deployment of these frightening devices to maximize effectiveness was discussed earlier. Ungulates adjust or habituate to frightening devices rather quickly, and these devices are generally not effective for an entire growing season. Recent research has evaluated the efficacy of animal-activated frightening devices, with mixed results (Belant et al. 1998*a*, Beringer et al. 2003, Gilsdorf et al. 2004*a,b*). Infrared beams or passive infrared sensors activate these new devices in the presence of ungulate-sized animals (Fig. 7). Beringer et al. (2003) significantly reduced soybean damage with a deer-activated system that played a randomly selected recording of sounds chosen to frighten ungulates (i.e., aggressive dogs, gunshot barrages, ungulate distress calls) and included an illuminated human effigy. Lasers, which are effective in dispersing some bird species, are ineffective on deer (VerCauteren et al. 2003*b*).

Fertility Control

Considerable effort has been expended to develop fertility control agents for, and methods of delivery to, ungulates. However, safe, practical, and cost-effective fertility control methods are not yet available (Fagerstone et al. 2002). It is unlikely that fertility control will become a viable ungulate management strategy in the near future (DeNicola et al. 2000).

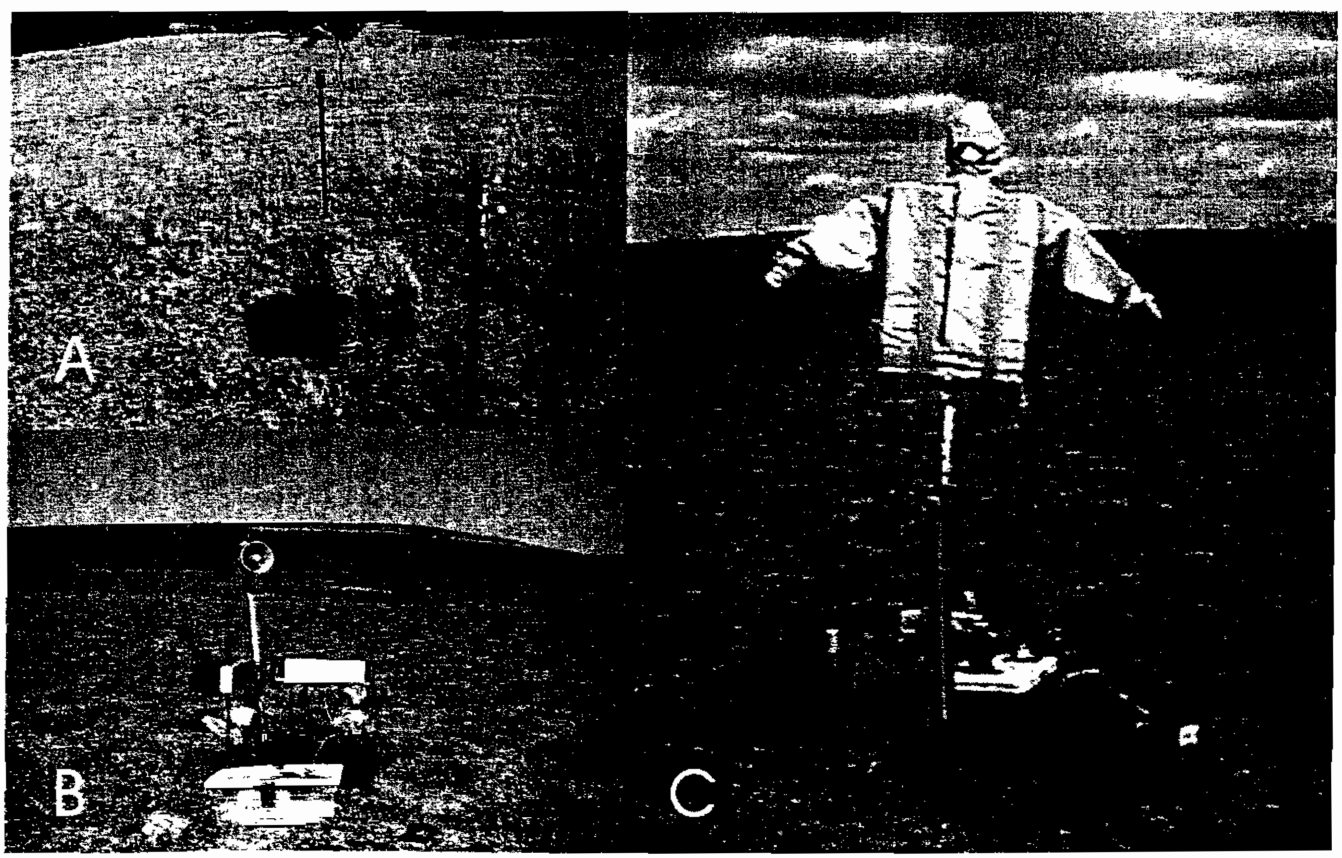

Fig. 7. Animal-activated frightening devices being developed to reduce deer damage include: A. motion- and heat-activated alarms positioned over bait. B. an infrared beam-triggered acoustic system that plays frightening sounds, and C. same as B with the addition of a pop-up effigy and strobe light.

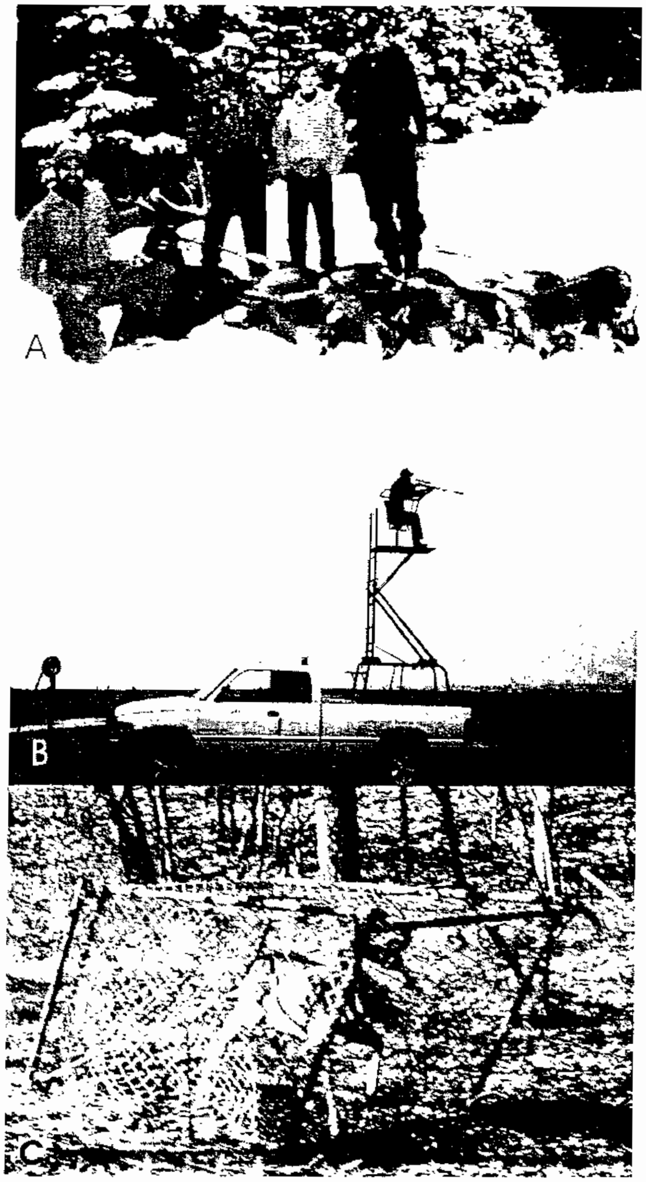

Fig. 8. Population control methods for deer include: A. well-managed hunting, B. sharp-shooting, and C. trapping (for euthanasia or translocation).

Hunting, Shooting, and Trapping

Regulated, managed hunting in rural settings is the most practical and effective method of managing overabundanr deer populations and controlling damage (Fig. 8A). It is also the most ecologically, socially, and fiscally responsible method. Some states have special depredation permits that can be issued to a landowner to remove a specific number of deer at a problem site outside the normal hunting season, if sufficient control cannot be achieved during the hunting season. Well-managed hunting can also be effective for reducing burgeoning deer numbers in urban settings. Several case studies have outlined straregies to ensure rhe success of deer hunts in areas thar are also populared with humans (McAninch 1995, VerCauteren and Hygnstrom 2002, Warren 2002). Professional sharpshooters have also been employed effectively to reduce deer numbers in areas where hunring was not considered safe (DeNicola et al. 2000) (Fig. 8B).

Deer can be captured with drop-door traps (Fig. 8C), rocket nets, drop nets, or tranquilizer guns, and then relocated or euthanized. However, these methods of deer removal are usually at least twice as expensive as shooting. In addition, there are problems with holding deer humanely in captivity until they can be transported somewhere for release, and with finding suitable release sites. In areas such as arboretums, where shooting is normally prohibited, the use of a skilled marksman under permit is probably preferable to live capture (Ishmael and Rongstad 1984). Live capture/transplanting is generally the control option of last resort, mandated by safety considerations or sensitive public relations issues.

RODENTS AND OTHER SMALL MAMMALS

Damage Assessment

Rodents and other small mammals are often not readily observed causing damage, and their damage is frequently difficult to measure and quantify. Likewise, accurate estimates of monetary losses of much of this damage are difficult to ascertain. Damage assessments indicate rodents and nonpredatory small mammals cause tremendous annual losses of food and fiber. Conover (2002) estimated the value of rodent damage to agriculture in the United States could be as high as $7 billion annually. In the timber industry, American beaver (*Castor canadensis*) and pocket gophers (Family Geomyidae) cause the most damage. Miller (1987) surveyed forest managers and natural resource agencies in 16 southeastern states and estimated annual wildlife-caused losses, primarily attributed to beaver, to be $11.2 million on 28.4 million ha. Comparatively, in 1998 Louisiana expended $2 million to control nutria (*Myocastor coypus*) (Bounds and Carowan 2000). Other types of damage include losses of sugarcane to rats (*Rattus* spp.), orchard damage by voles (*Microtus* spp.), and decreased forage quantity on rangelands caused by rodents, rabbits, and hares (Fig. 9). In households, house mice (*Mus musculus*) are the primary species conflicting with humans.

Quantifying losses to evaluate efficacy of techniques can be challenging. Most research compares plors where the resource was protected to those with no protection, or production in areas with no rodents to areas with rodents. However, loss estimates must be converted to accurate assessments of dollar losses to compare cost/benefit evaluation of control programs (VerCauteren et al. 2002*b*). Conversion to dollars is often difficult, given the vast areas involved and variability in rodent populations. Given these considerations and the complexiry of damage situations, it is easy to realize the need for better monitoring techniques, damage assessment methods, and control effort evaluation.

Species Damage Identification

Most wild mammals are secretive and not easily observed; many are nocrurnal. Often the investigator must rely on sign, such as tracks, trails, tooth marks, feces, or burrows to identify the species responsible for damage. Trapping may be necessary to make a positive identification of damage-causing small rodents; frequently, more than one species is involved.

Characteristics of the damage may provide clues to the species involved. In orchards, for example, major strip-